INL/CON-06-01091
PREPRINT

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ANS Annual Meeting

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June 2006

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INTRODUCTION

The US Department of Energy is investigating the use of high-temperature gas-cooled reactors (HTGR) to produce electricity and hydrogen. Although the hydrogen production processes using the nuclear energy are in an early stage of development, coupling hydrogen plant to HTGR requires both efficient heat transfer and adequate separation of the facilities to assure that off-normal events in the production facility do not impact the nuclear plant.

In anticipation of the design, development and procurement of an advanced power conversion system for HTGR, this study was initiated to identify the major design and technology options and their tradeoffs in the evaluation of power conversion system (PCS) coupled to hydrogen plant. In this study, we investigated a number of design configurations and performed thermal hydraulic analyses using various working fluids and various conditions. This paper includes a portion of thermal hydraulic results based on a direct cycle and a parallel intermediate heat exchanger (IHX) configuration option.

BASE DESIGN CONFIGURATION

A number of plant configurations were evaluated as part of this study. Among those configurations, we selected one configuration as the base design which is a direct electrical and a parallel IHX shown in Figure 1. In this configuration, the hot fluid from the reactor outlet is split, with most going towards the PCU and the remainder going towards the hydrogen production plant. This configuration is more complicated, but results in a higher overall efficiency because both the electrical and hydrogen production plants see the maximum possible inlet temperature to PCU and intermediate heat transfer loop (IHTC). With the parallel option, a small compressor or blower is required to compensate for the pressure loss across the IHX and to allow the fluid streams to mix downstream of the recuperator.

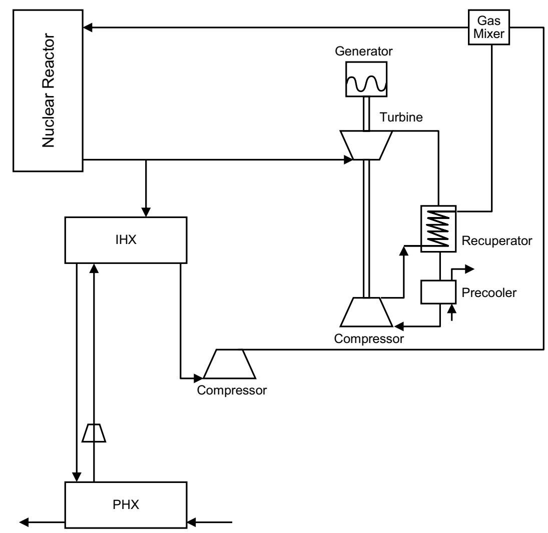

Figure 1. Direct electrical cycle and a parallel IHX.

EFFECTS OF SEPARATION DISTANCE

Estimates for the required separation distance between the nuclear and hydrogen plants depend on the design and safety criteria applied and vary considerably from 60 m to 500 m [Verfondern and Nishihara (2004) and Sochet et al. (2004)]. However, a recent study by Smith et al. [2005] reveals that a 60 m to 120 m is adequate. Therefore, a nominal value of 90 m was used, with parametric variations between 60 and 500 m. The separation distance primarily affects the diameters and insulation requirements of the hot and cold legs in the heat transport loop.

RESULTS

The effects of separation distance between the nuclear and hydrogen plants on the required inner diameters for the hot and cold legs of the IHTC are shown in Figure 2 for low-pressure helium. The required diameters decreased by 8% when the separation distance was decreased from 90 to 60 m. The required diameters increased by 52% when the separation distance increased from 90 to 500 m. Almost identical percentage changes were obtained for Flinak. Thus, the separation distance has a significant effect on the required diameters of the hot and cold legs of the intermediate heat transport loop.

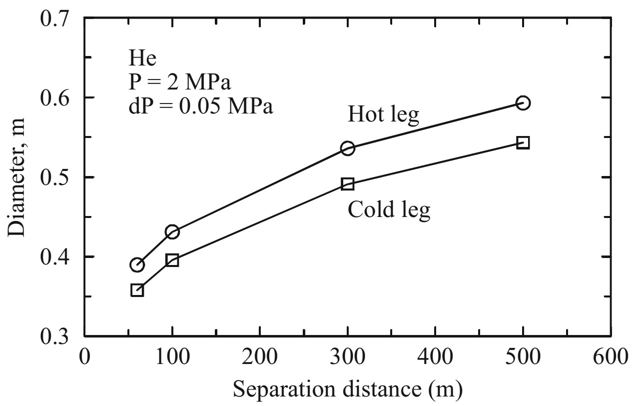

Figure 2. The effects of separation distance on pipe diameters.

WORKING FLUIDS

The effects of the working fluid on various parameters are summarized in Table 1. The volumes of the IHX and process hydrogen heat exchanger (PHX) were 15 and 35% smaller, respectively, when the working fluid was $NaBF_4$-NaF than when it was helium. The relative effect of the working fluid was different between the two heat exchangers because of variations in the log-mean temperature difference between heat exchangers. In the IHX, the log-mean temperature difference was the same for both working fluids, and the difference in size was a consequence of the better heat transport properties of the liquid salt. The log-mean temperature difference across the PHX was smaller with helium as the working fluid because the larger pumping power resulted in a significant temperature rise across the compressor. Thus, the effect of the working fluid on the PHX volume was a consequence of the better heat transport properties of the liquid salt coupled with the larger temperature difference.

Parameter	He/He	He/ $NaBF_4$-NaF
IHX:		
Log-mean temperature difference, °C	26	26
Hot / cold fluid pressure drop, Pa	5.0E4 / 1.7E5	5.0E4 / 6.9E3
Hot / cold fluid pumping power, W	3.4E6 / 3.72E7	3.4E6 / 3.6E3
Hot /cold fluid Reynolds number	1330 / 1356	1440 / 240
Width, m	5.12	4.92
Length, m	1.52	1.40
Volume, m^3	39.8	33.9
PHX:		
Log-mean temperature difference, °C	48	63
Hot fluid pressure drop, Pa	5.0E4	2.0E3
Hot fluid pumping power, W	1.12E7	1.0E3
Hot fluid Reynolds number	1.5E4	4.4E3
Shell inner diameter, m	3.73	2.72
Length, m	12.4	15.1
Volume, m^3	135	87.7
Number of tubes	4.4E4	2.4E4
Hot / cold legs:		
Inner diameter, m	1.09 / 1.00	0.29 / 0.28
Insulation thickness, m	0.019 / 0.017	0.0032 / 0.0020
Differential pressure, Pa	5.0E4 / 5.0E4	3.0E5 / 3.0E5
Pumping power, W	1.12E7 / 1.12E7	1.6E5 / 1.6E5
Heat loss, W	1.25E6 / 5.4E5	1.25E6 / 5.4E5
Reynolds number	6.6E6 / 9.8E6	7.1E6 / 2.5E6

Table 1. Intermediate heat transport loop parameters.

CONCLUSIONS

The use of a liquid salt as the working fluid in the intermediate heat transport loop of the dual-purpose facility analyzed here causes the overall efficiency to increase by 0.2 – 0.6% compared to low-pressure helium because of reduced pumping power. However, as additional power is delivered to hydrogen plant, advantages of liquid salt as a coolant in the intermediate heat transport loop will become more pronounced.

ACKNOWLEDGMENT

This work was supported through the Department of Energy's NERI and Power Conversion Program under DOE Idaho Operations Office Contract DE-AC07-99ID13727.

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